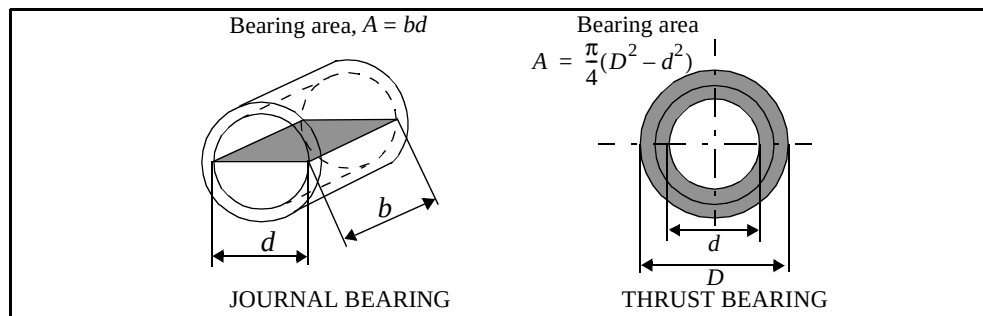


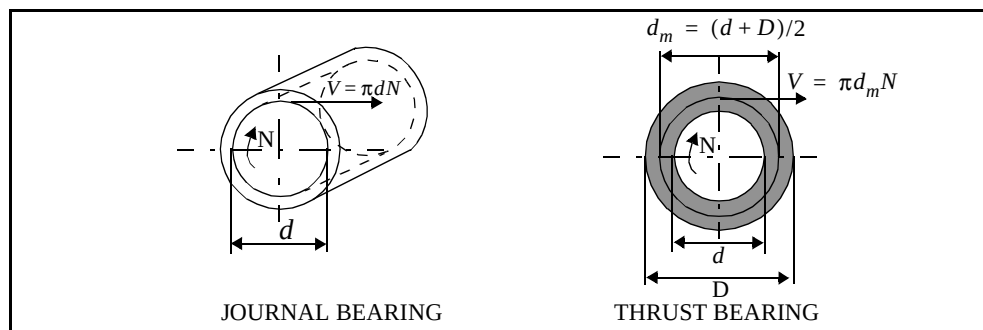
FRICITION IN BEARINGS

1. NOTATION AND UNITS

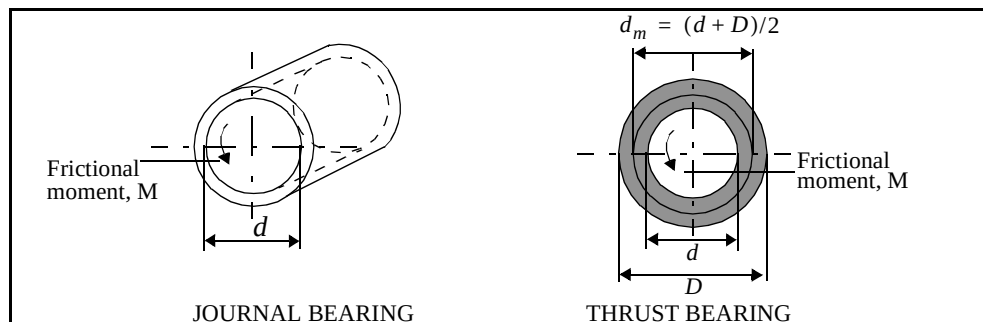
P bearing pressure or specific loading defined as the bearing load divided by the area of the bearing. The area of the bearing is always taken to be the area available for carrying the load projected onto a plane that is perpendicular to the load vector. In simple pad bearings and thrust bearings this area will be the same as the nominal area of the bearing. However, in journal bearings for example, the bearing area is simply the journal diameter multiplied by the axial length of the bearing. N/m^2



V equivalent sliding speed of the bearing. In journal bearings the sliding speed is evaluated at the periphery of the journal and is simply πdN where d is the diameter of the journal and N is the rotational speed of the journal relative to the bearing. In thrust bearings, however, the sliding speed is of necessity evaluated at the mean diameter of the bearing. m/s

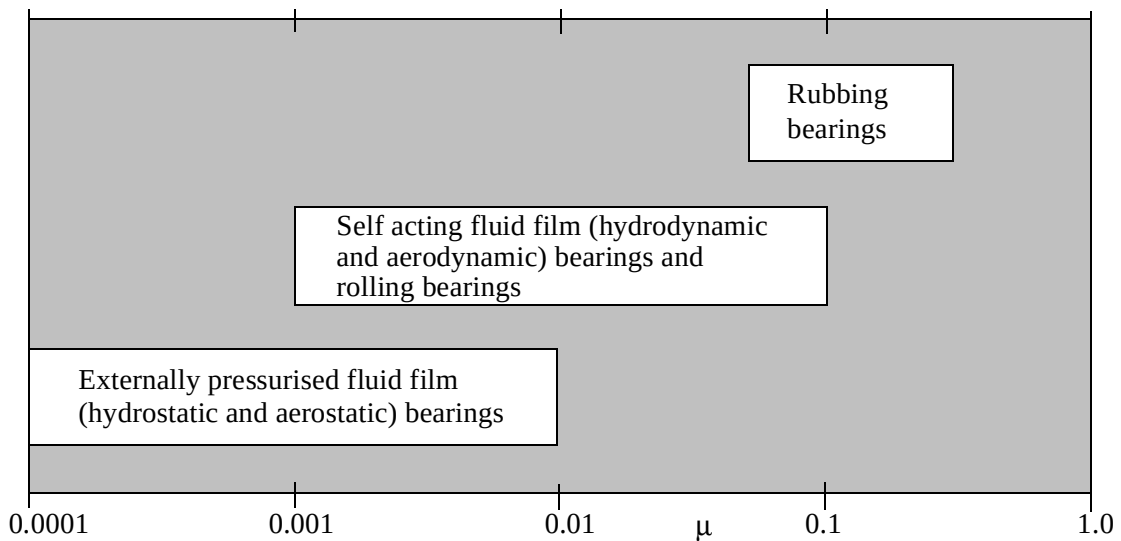


μ coefficient of friction defined as the frictional force divided by the bearing load in translational motion. In rotary motion, the coefficient of friction is defined in terms of the frictional torque, M , as $2M/Wd$ in journal bearings and $2M/Wd_m$ in thrust bearings, where W is the bearing load. The power loss is obtained by multiplying the coefficient of kinetic friction by the load and the equivalent sliding speed.



2. INTRODUCTION

This Item indicates the ranges of the coefficients of friction to be expected in industrial bearings. Where appropriate, the variation of the coefficient of friction with operating parameters for a particular example of each type of bearing is indicated. Only those bearings in which direct rubbing and rolling of contacting surfaces occurs or in which the surfaces are separated by fluid pressures within a lubricating film are considered. Other bearings, such as magnetic bearings and flexural pivots (see Reference 1) in which friction is potentially absent, are not considered.

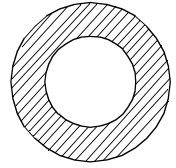


Sketch 2.1 Order of magnitude of the coefficient of friction in the major classes of bearing

The coefficients of friction in the bearings considered cover several orders of magnitude as indicated in Sketch 2.1. Rubbing bearings, which include both dry rubbing bearings and boundary lubricated bearings, display the highest coefficients of friction, usually in the range 0.05 to 0.3 although values outside of this range are possible. In those fluid film bearings in which the lubricating film is maintained by the relative motion of opposing surfaces, such as hydrodynamic bearings and self acting gas bearings (aerodynamic bearings), the coefficient of friction is commonly in the range 0.001 to 0.01 although values up to or beyond 0.1 are found in high speed, lightly loaded applications. In externally pressurised bearings (hydrostatic and aerostatic bearings) maintenance of a lubricating film does not rely on relative motion and coefficients of friction less than 0.001 are commonly displayed. As a class, rolling bearings display coefficients of friction similar to those of hydrodynamic and aerodynamic bearings although the coefficients of friction of the two types of bearings will not necessarily be similar in specific applications.

3. RUBBING BEARINGS

Direct rubbing contact without the benefit of a separating fluid film is found in low speed parts in domestic and industrial applications, motor vehicle linkages, hinges and catches, small boat tackle, instrument spindles, electro-mechanical audio/visual and copying equipment, cameras, toys, clockwork mechanisms, materials handling and packaging machines. Other examples are to be found in the food processing industries and whenever operation in vacuum or at extremes of temperature is required. Direct rubbing contact may also occur between machine components and the process material in textile machines. Rubbing contact is characterised by a kinetic friction which is substantially independent of the nominal contact area and the viscosity of any liquids present.



SURFACE FILMS

Most engineering components in rubbing contact, especially metal components, will be protected by surface films which will either be fortuitously present or will have been applied by some process, often for the purposes of combating wear (see Reference 2).

- Oxide films and other coatings
- Hardened surface layers.
- Absorbed films of, for example, fatty acids.
- Sulphur and phosphorus containing films formed by chemical reaction with “active” oil additives.
- Films of certain lamellar (plate like structure) solids such as graphite and MoS_2 .
- Films of low shear strength metals such as lead and tin.
- Conversion coatings such as provided by phosphating.

RUBBING CONTACT

The term rubbing is here used to denote situations in which opposing component surfaces are in nominally direct rubbing contact and any fluid present plays no significant part in physically separating the surfaces.

FRICTION WITH LIQUIDS

The presence of a liquid does not necessarily reduce friction unless the liquid has favourable boundary lubricating properties. Even so, any reduction in friction is rarely significant except with metallic surfaces.

3.1 Metallic Materials Rubbing on Metallic or Ceramic Counterfaces

Application

Examples of metallic components rubbing on metallic or ceramic counterfaces can be found in almost every machine. Commonly, a mineral oil or grease with, perhaps, lubrication enhancing additives will be present. However, dry operation is possible with protective coatings and treatments or with special solid lubricant impregnated metals.

Coefficients of friction in practice

The coefficient of kinetic friction between untreated metal surfaces may, typically, be in the range of 0.4 to 1.0 when only protected by the natural oxide film that is inevitably present in air applications. However, in most engineering applications additional protection of the surfaces will have been provided and coefficients of friction in the range 0.05 to 0.2 are then usual. The lower values of friction coefficient within this range are usually only obtained where some form of chemically active boundary lubricant is present although similarly low values are also possible with some solid lubricant films at high loadings.

Coefficient of friction in particular cases

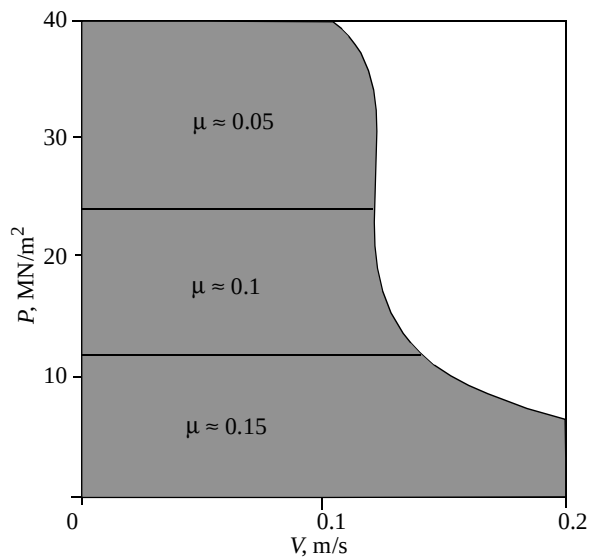
In particular metallic bearings the variation of the coefficient of friction with specific load, P , and sliding speed, V , depends on the nature of the film protecting the surfaces. In the example of a graphite impregnated bronze bearing (see Sketch 3.1) the coefficient friction is insensitive to sliding speed and decreases with specific loading. A similar variation of the coefficient of friction might be expected with metallic components that have been given a graphite-containing surface coating (see Reference 2). A quite different behaviour is exhibited in the example of a boundary lubricated bearing. In this particular bearing (see Sketch 3.1) the coefficient of friction increases with both specific load and sliding speed. In all bearings that rely on a thin protective film, breakdown of the film and an abrupt increase in friction can occur at a particular temperature and loading.

METALLIC MATERIALS ON METALLIC OR CERAMIC COUNTERFACES

Typical μ : 0.05 to 0.2

Applications :

- Boundary lubricated sleeve bearings in earth moving and agricultural equipment.
- Machine tool slideways.
- Aircraft control surface bearings.
- Bearings in mining equipment and the offshore industry.
- General low duty bearings.



VARIATION OF μ FOR GRAPHITE IMPREGNATED BRONZE BEARING

EXAMPLE 1 SOLID LUBRICANT BEARINGS

This example is of a 0.03 m diameter hardened steel journal rotating intermittently in a graphite impregnated bronze bearing (material G1 of Reference 3). Dry operation at an ambient temperature of 100°C has been assumed.

SOLID LUBRICANT COATINGS

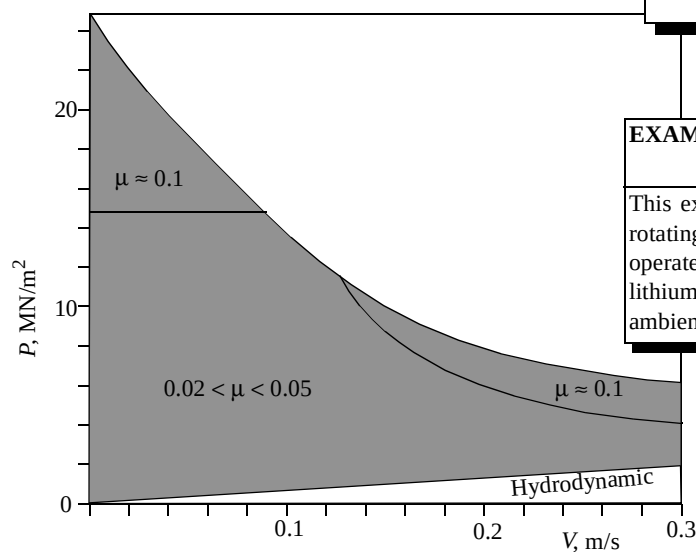
Similar values of μ are obtained between contacting metallic components that have been given a solid lubricant coating.

POROUS METAL BEARINGS

Oil impregnated porous metal bearings can operate as hydrodynamic film bearings under ideal conditions but they more typically operate with much thinner lubricant films (in the so-called mixed lubrication regime) with a coefficient of friction in the range 0.02 to 0.05.

MACHINE TOOL SLIDEWAYS

Plain machine tool slideways often operate with boundary lubrication and a coefficient of friction of about 0.2. However, their tribological behaviour depends critically on surface topography (see Reference 4) and with very careful design it is possible for hydrodynamic lubricating films to be developed at normal working sliding speeds (usually up to 200 mm/min) and for coefficients of friction between 0.01 and 0.05 to be attained.



VARIATION OF μ FOR LEADED BRONZE WITH GOOD BOUNDARY LUBRICATION

EXAMPLE 2 BOUNDARY LUBRICATED BEARINGS

This example is of a 0.03 m diameter hardened steel journal rotating continuously in a leaded bronze bearing designed to operate with good boundary lubrication such as provided by a lithium – hydroxystearate petroleum base grease. Normal ambient temperature has been assumed.

Sketch 3.1

3.2 Polymer Based Materials Rubbing on Metallic or Ceramic Counterfaces

Application

Polymer based materials for rubbing bearing applications include both filled and unfilled thermoplastics as well as reinforced thermosets and thin layer materials consisting of a polymer bearing layer on a metallic or plastic based backing. Rubbing bearings utilising polymer based materials are found in numerous applications from consumer durables to nuclear reactor plant and aircraft. In many of these applications the bearings operate dry although liquid contaminants such as water may be present. In some applications additional grease lubrication is applied.

Coefficients of friction in practice

The coefficient of kinetic friction of polymer based materials rubbing on metallic or ceramic counterfaces can exceed unity with materials such as rubber. However, with the materials that find application as rubbing bearings (see Reference 3) coefficients of friction between 0.05 and 0.3 are usual. The lower values of friction coefficient within this range are usually only obtained with materials incorporating a PTFE based surface layer (so called thin-layer materials). Although liquids with effective boundary lubricating properties for polymers are known, in general the coefficient of friction in the presence of liquids is little different from that in their absence.

Coefficient of friction in particular cases

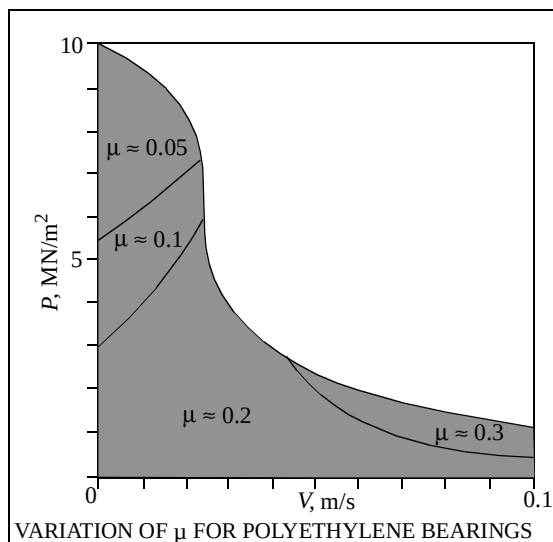
In particular bearings the coefficient of friction depends primarily on the specific loading and the rubbing speed. The three example bearings considered in Sketch 3.2, utilise materials displaying quite distinct behaviours. With filled PTFE materials the coefficient of friction is typically insensitive to temperature (and hence to rubbing speed). With materials such as polyethylene, however, friction increases with rubbing speed while with most thin layer materials the friction decreases.

POLYMER BASED MATERIALS ON METALLIC OR CERAMIC COUNTERFACES

Typical μ : 0.05 to 0.3

Applications :

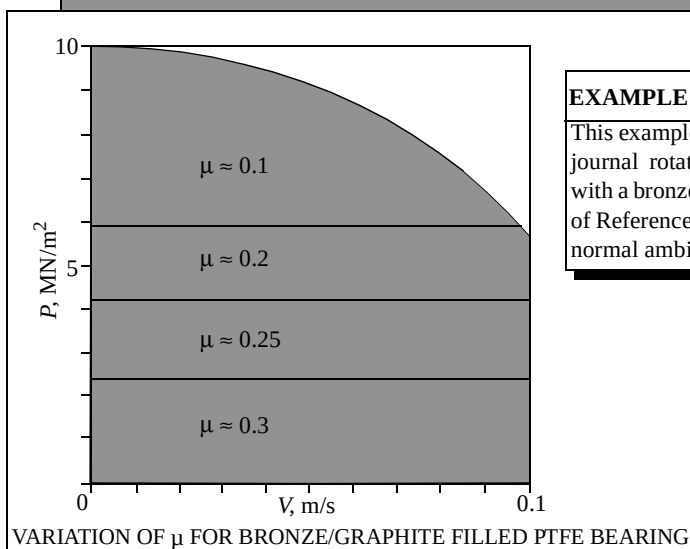
- Brushes and thrust washers in consumer durables, office equipment and automobiles.
- Aircraft control and undercarriage bearings.
- Spindle bearings in textile and food processing machinery and in materials handling equipment.
- Journal, thrust and slideway bearings in gate valves and similar mechanisms operating with water and/or abrasives.
- Specialised nuclear industry bearings and cryogenic bearings.

**EXAMPLE 1 POLYETHYLENE BEARINGS**

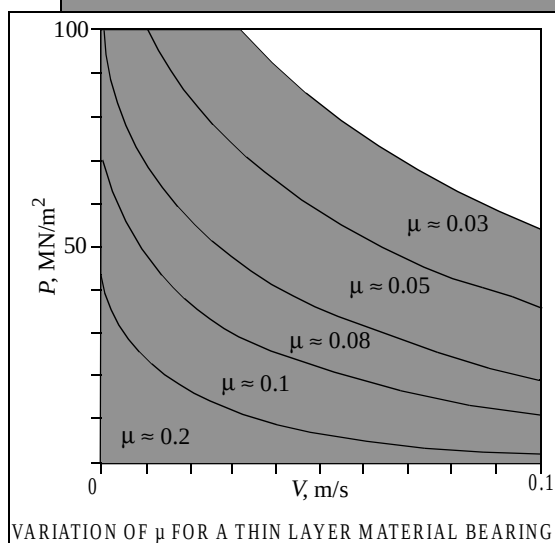
This example is of a 0.03 m diameter stainless steel journal rotating intermittently in a bearing lined with an ultra high molecular weight (UHMW) polyethylene (material A5 of Reference 3). Dry operation has been assumed at normal ambient temperature.

NOTE

The indicated values of μ are attainable in well designed bearings where the material has been carefully chosen for the operating conditions (see Reference 3). Higher values may apply in individual cases

**EXAMPLE 2 FILLED PTFE BEARING**

This example is of a 0.03 m diameter stainless steel journal rotating intermittently in a bearing lined with a bronze and graphite filled PTFE (material E8 of Reference 3). Dry operation has been assumed at normal ambient temperature.

**EXAMPLE 3 THIN LAYER MATERIAL BEARING**

This example is of a 0.03 m diameter stainless steel journal rotating intermittently in a bearing lined with a thin layer material consisting of a PTFE/lead/bronze sinter on a steel backing (material D1 of Reference 3). Dry operation has been assumed at normal ambient temperature.

FRICTION OF PTFE

The low friction properties PTFE are sometimes overstated. Coefficients of friction as low as 0.02 are possible but only at very low rubbing speeds and high loadings. The starting coefficient of friction can be extremely high in bearings that have been stationary under load.

Sketch 3.2